Implementing Trojan-Resilient Hardware from (Mostly) Untrusted Components Designed by Colluding Manufacturers

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Sebastian Faust François-Xavier Standaert

European Research Council
Established by the European Commission

Outline

Introduction

Private Circuits 3

Targeted algorithm

Hardware Design

Conclusion

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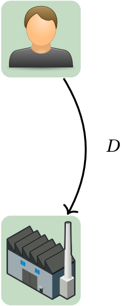

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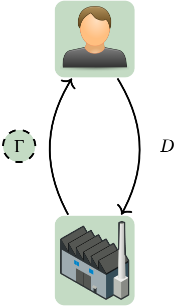

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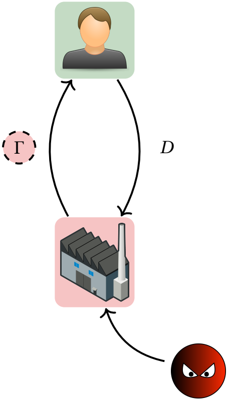

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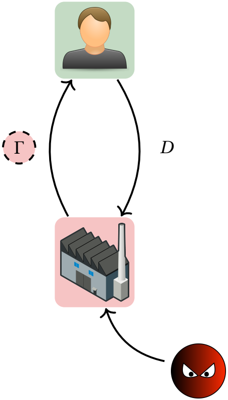

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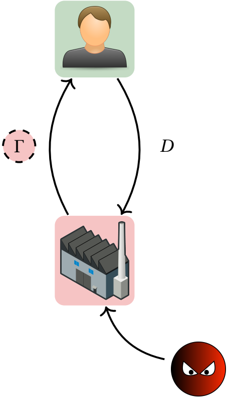

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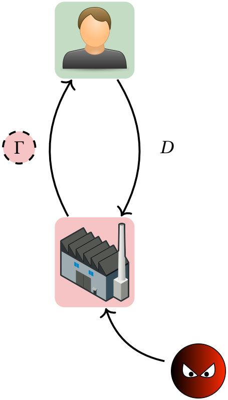

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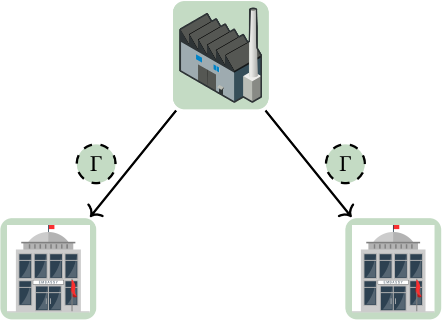

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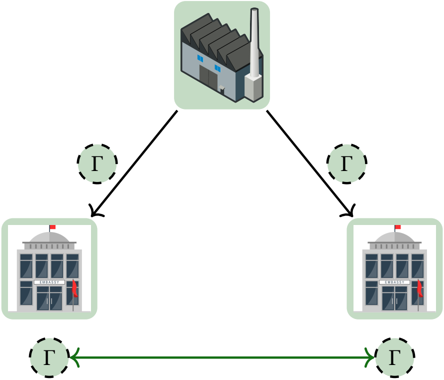

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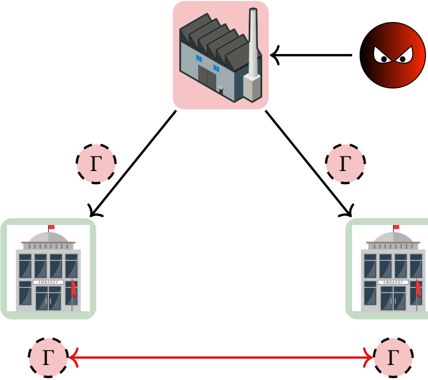

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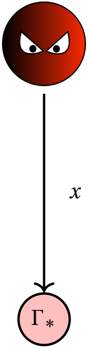

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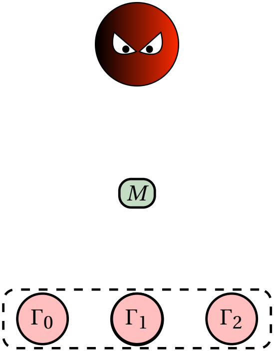

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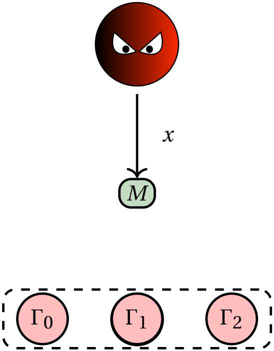

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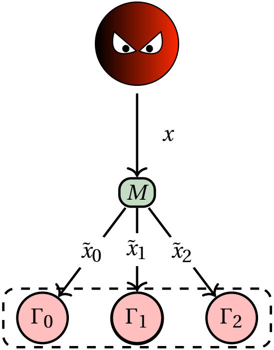

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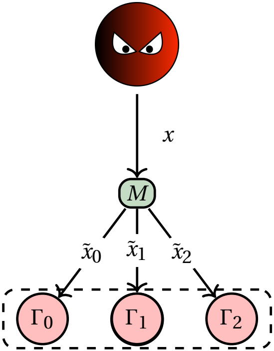

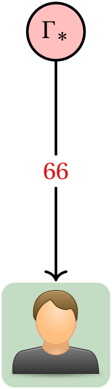

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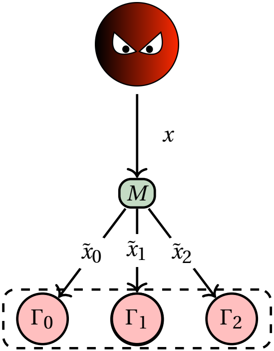

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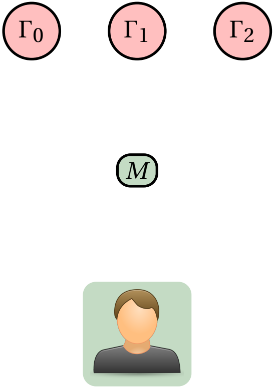

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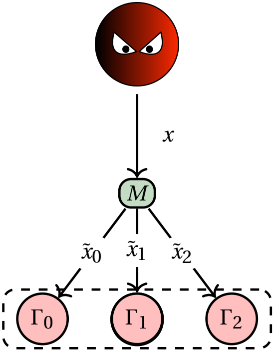

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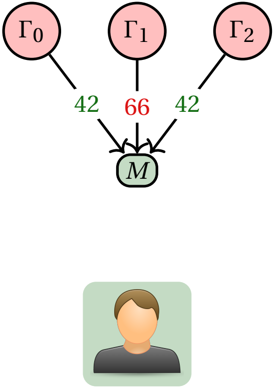

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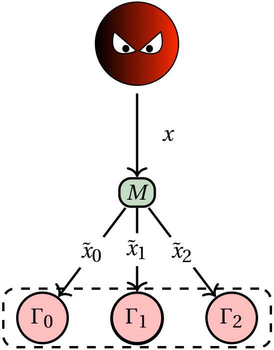

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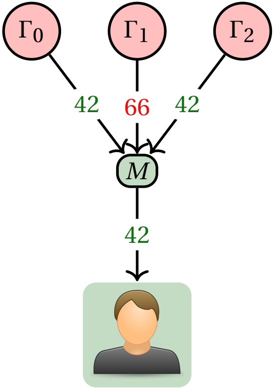
- Perform trusted majority vote among them.



Countermeasure: Compiling and Testing

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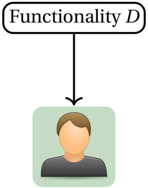

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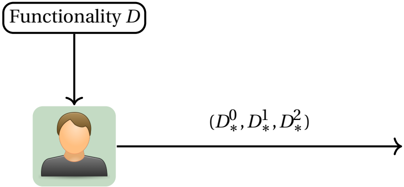

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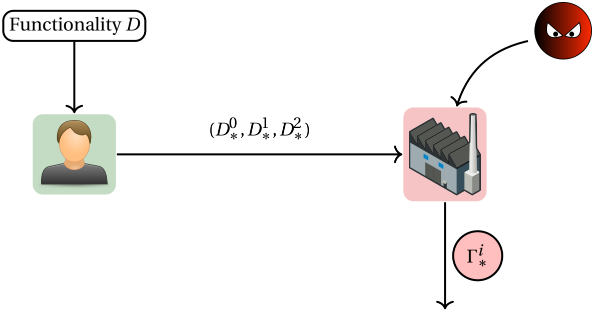

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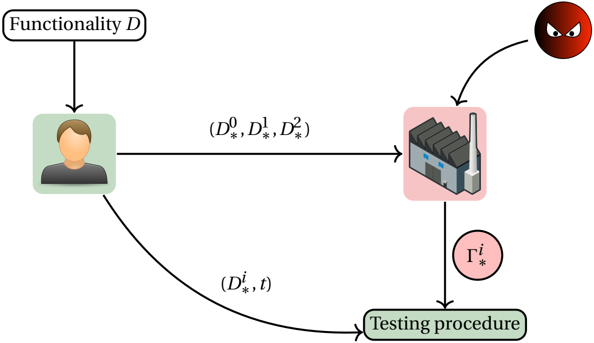

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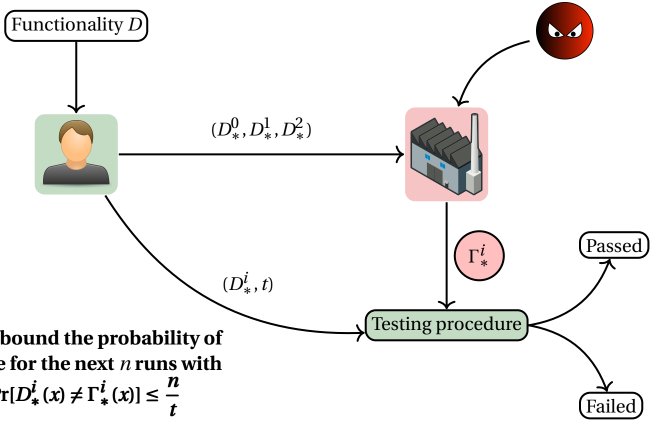

Tests bound the probability of failure for the next n runs with $\Pr[D_*^i(x) \neq \Gamma_*^i(x)] \leq \frac{n}{t}$

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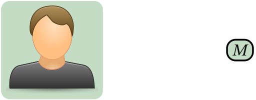

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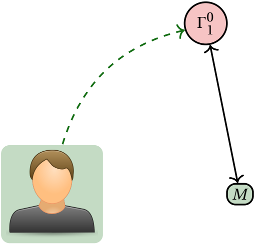

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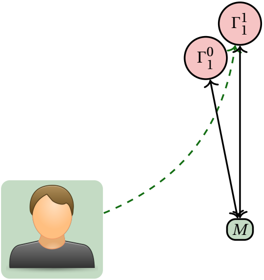

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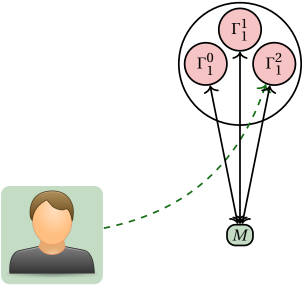

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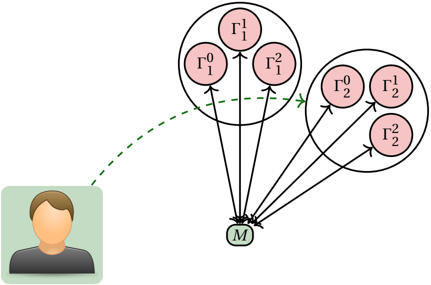

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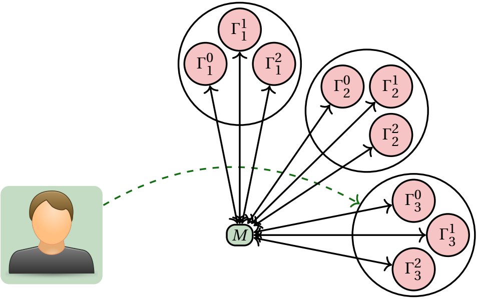

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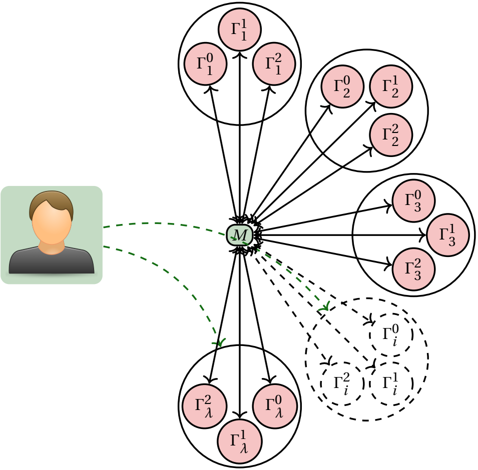

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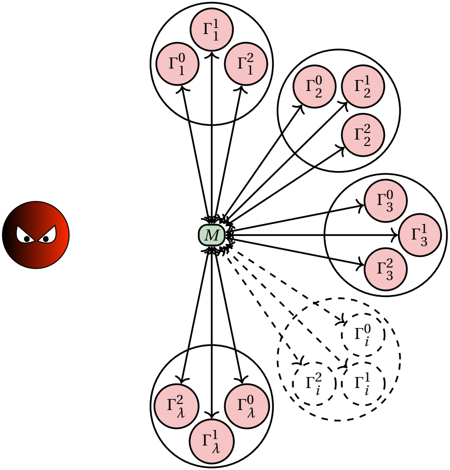

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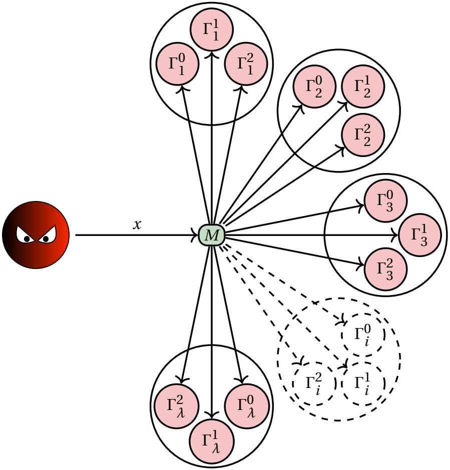

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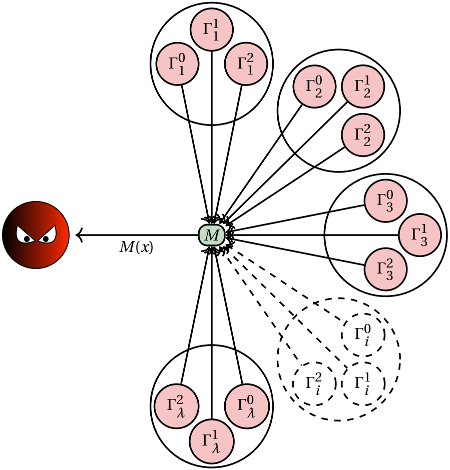

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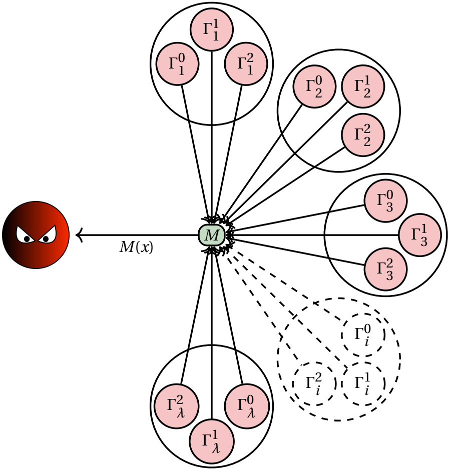

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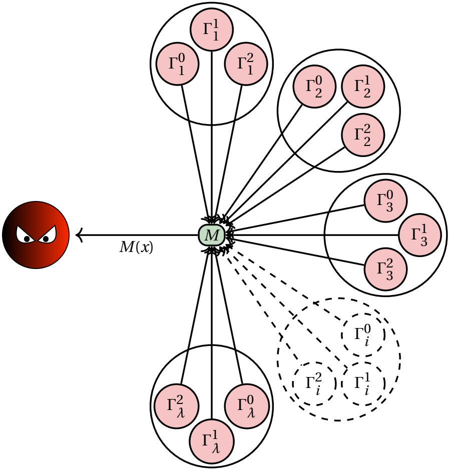

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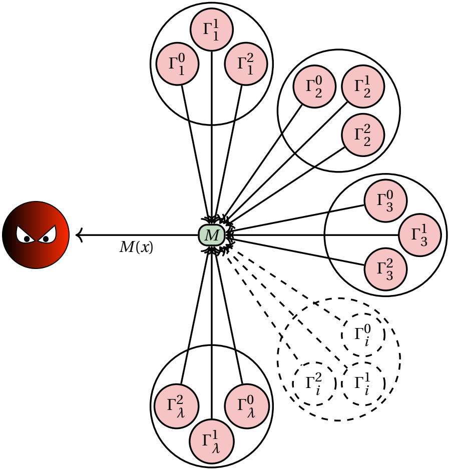

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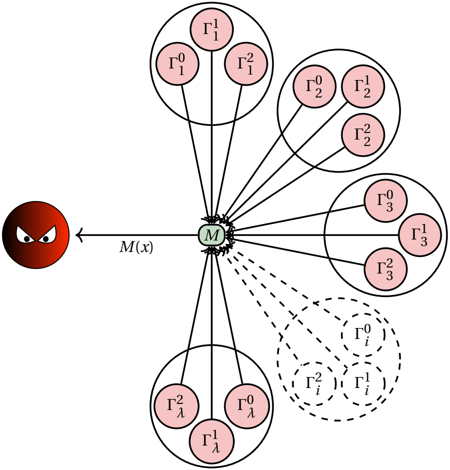

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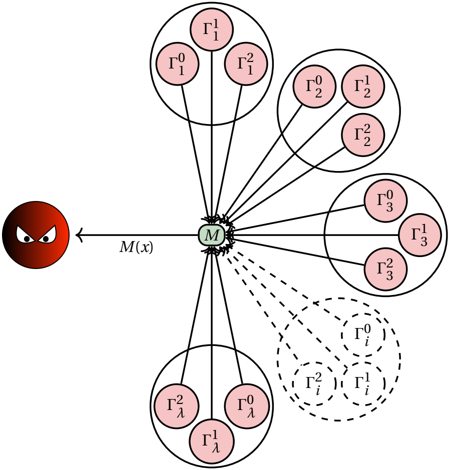

No need for non colluding manufacturers thanks to combination of:
Passive secure multi-party computation
Test amplification

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Targeted Robustness level:

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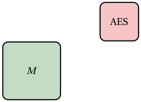

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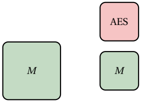

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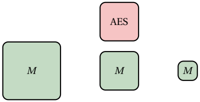

Speed

- Get higher encryption throughput
- Increase number of tests t

Design goals

Targeted Robustness level:

$$\Pr[M(x) \neq D(x)] \leq \left(\frac{n}{t}\right)^{\lambda/2} \leq 2^{-80}$$

Methodology:

1. Fix the number of online runs n
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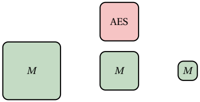

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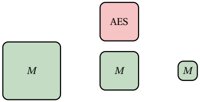

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1. First Private Circuit 3 implementation
2. Algorithm: protocol and blockcipher
3. One order of magnitude smaller trusted circuits

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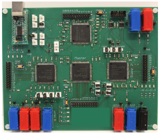

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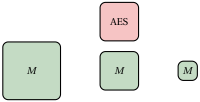

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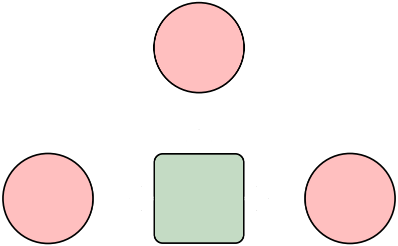
Secret Sharing



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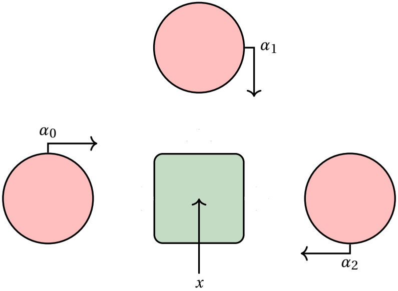

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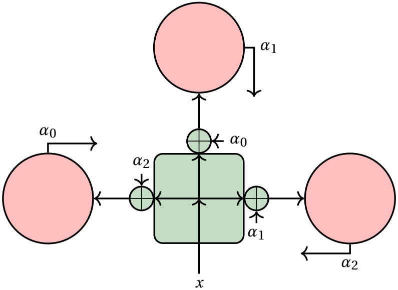

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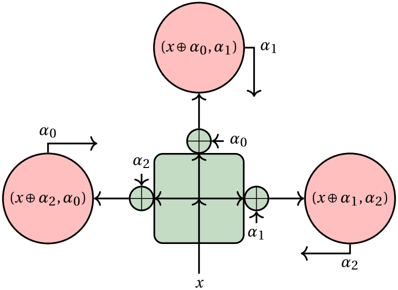

Secret Addition

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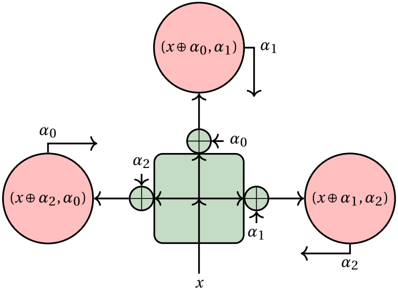

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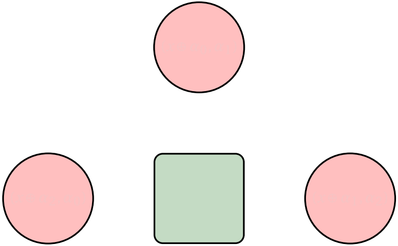

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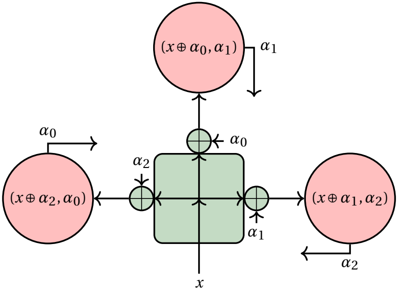

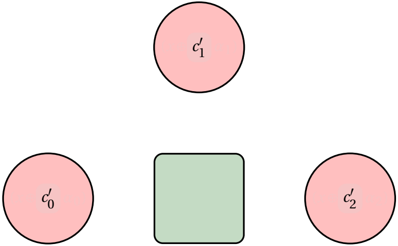

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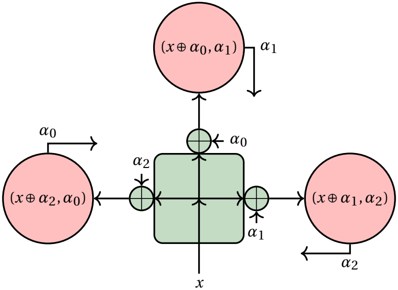

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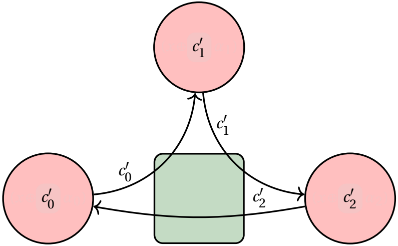

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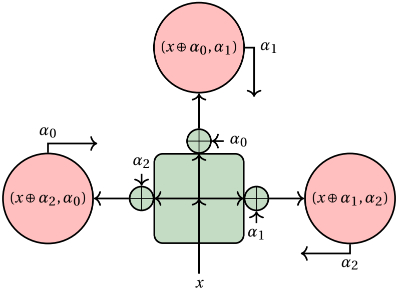

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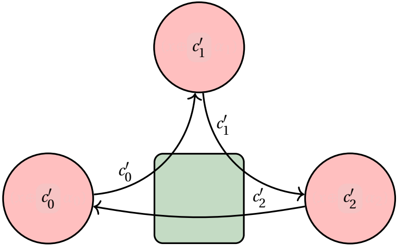

Can build any functions

- No memory is needed in the master, only rooting and xoring
- A single element needs to be sent for multiplication

Blockcipher: Rijndael AES Sbox

Speed depends on:

- Number of rounds
- Number of Sbox's per round
- Bits to exchange per Sbox.

Cipher	# of **rounds**	**Sbox per round**	**bits per enc.**

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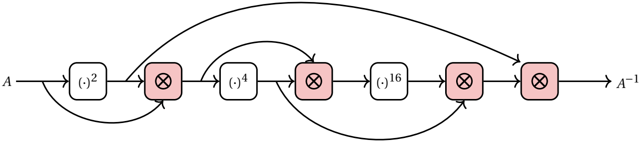

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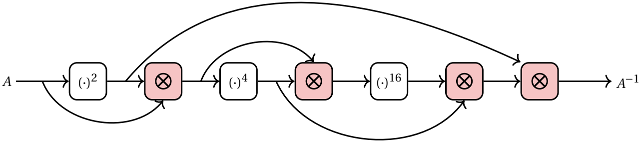

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32-bits transfer

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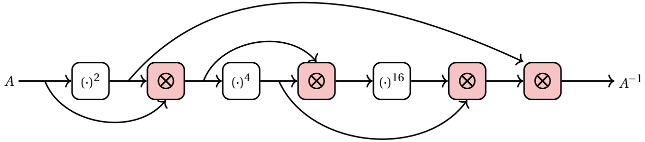

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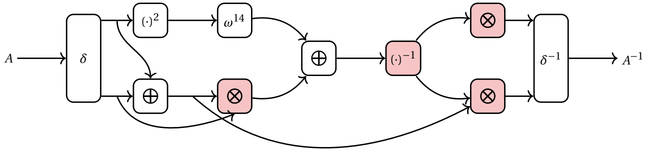

Advanced AES Sbox

Blockcipher: Rijndael AES Sbox

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Cipher	# of **rounds**	**Sbox per round**	**bits per enc.**
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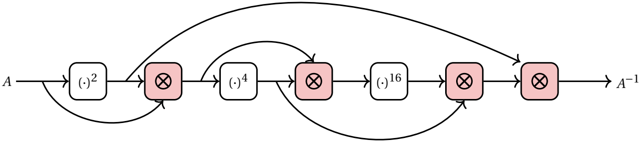

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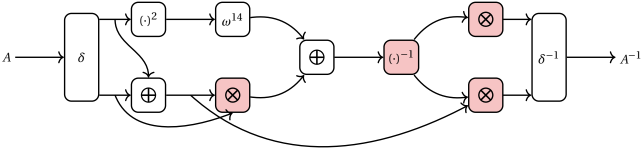

5 mult. over
GF(2^4)
20-bits transfer

Advanced AES Sbox

Blockcipher: Mysterion Sbox

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- Mysterion is 128 bits blockcipher based on SPN

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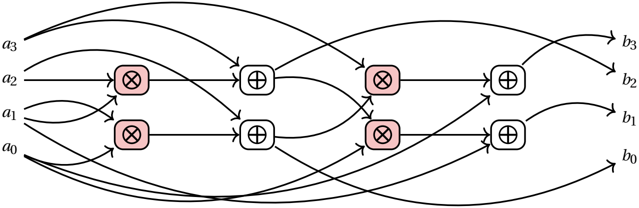

Mysterion Sbox

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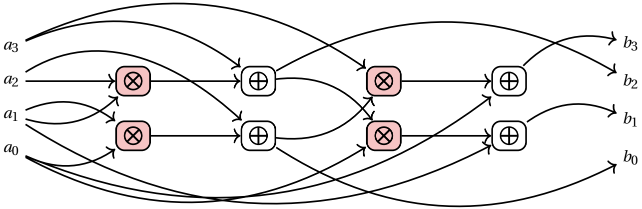

4 mult. over GF(2)
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Mysterion Sbox

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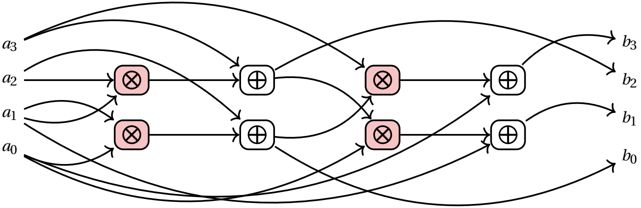
Bottleneck if fed fast enough
No restriction on the mini-circuits



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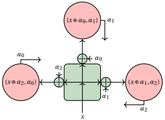

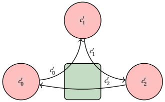

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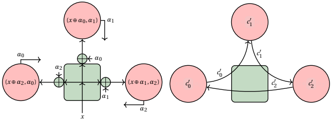

The bus needs to be full duplex to avoid registers in the trusted circuit.

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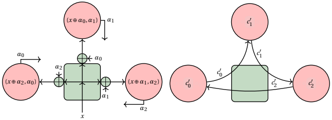

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Parallel bus on N bits

Serial bus on 1 bits

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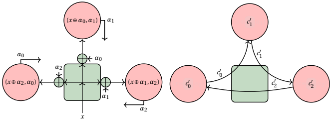

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Parallel bus on *N* bits

- Allows to send *N* bits at the time in a full duplex manner .

Serial bus on 1 bits

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Bus		**AES**		**Mysterion**	
Throug. [Gbps]	**N** [bit]	**Cycles** [cycle]	**Through.** [Mbps]	**Cycles** [cycle]	**Through.** [Mbps]
1.5	1	180	55	96	107
6	4	46	222	24	428

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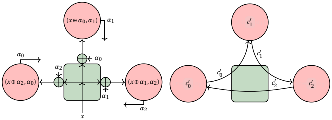

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Parallel bus on N bits

- Allows to send N bits at the time in a full duplex manner .
- The master needs to duplicate N times XOR gates and routing.

Serial bus on 1 bits

- Allows to send 1 bits at the time in a full duplex manner.
- The master do not need to duplicate XOR gates and routing ✓ .

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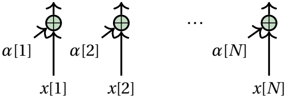

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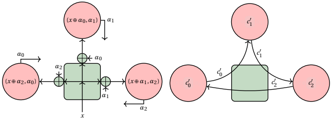

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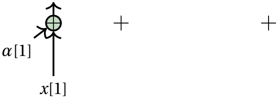

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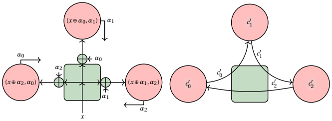

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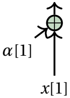

The bus used is Serial to have 16[GE] per sub-circuit ✓

The number of bits to exchange is the critical part for data throughput.

Majority vote

The Majority vote among λ bits
is the most expensive operation.

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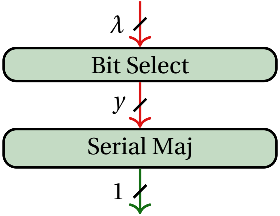

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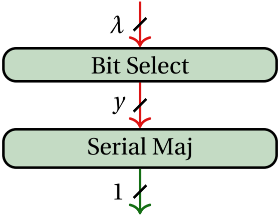
$$\lambda = 1 \xrightarrow{\text{Enc.}} \xrightarrow{\text{Maj.}}$$



Extrapolated AES data throughput

λ	**1**
Throug. [Mbps]	55

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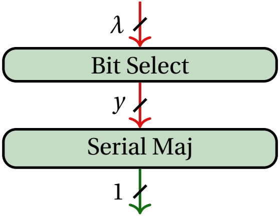
$$\lambda = 1 \quad \xrightarrow{\text{Enc.}} \; \xrightarrow{\text{Maj.}}$$

$$\lambda = 4 \quad \xrightarrow{\text{Enc.}} \; \xrightarrow{\text{Maj.}}$$



Extrapolated AES data throughput

λ	**1**	**2**	**4**
Throug. [Mbps]	55	51.4	46.3

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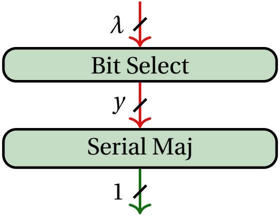


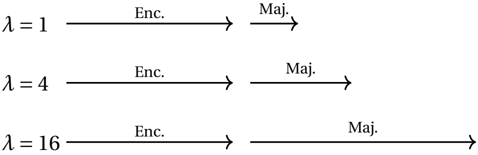
λ

Bit Select

y

Serial Maj

1



$\lambda = 1$ Enc. Maj.

$\lambda = 4$ Enc. Maj.

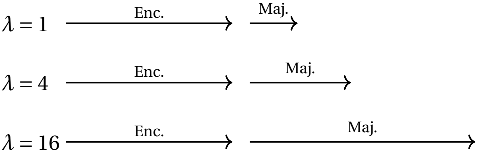
$\lambda = 16$ Enc. Maj.

Extrapolated AES data throughput

$\boldsymbol{\lambda}$	**1**	**2**	**4**	**8**	**16**
Throug. [Mbps]	55	51.4	46.3	38.7	29.1

Majority vote

The Majority vote among λ bits is the most expensive operation.



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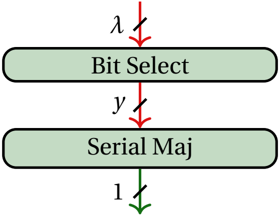


λ

Bit Select

y

Serial Maj

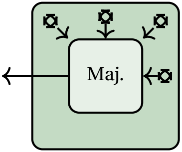
1

Extrapolated AES data throughput

$\boldsymbol{\lambda}$	**1**	**2**	**4**	**8**	**16**
Throug. [Mbps]	55	51.4	46.3	38.7	29.1

Majority vote area [GEs]

λ	**Bit select.**	**Serial Maj.**	**Total**
8	44	52	96
16	77.6	67	144.6



Maj.

Robustness bounds

Methodology:

$$\Pr[M(x) \neq D(x)] = \left(\frac{n}{t}\right)^{\lambda/2} \leq 2^{-80}$$

Robustness bounds

t [days]	**n** [bits]	**AES**			**Mysterion**		
		λ	**ROB.**	**Area** [GEs]	λ	**ROB.**	**Area** [GEs]
1	10^3	6	2^{-95}	181	5	2^{-81}	144
	10^6	8	2^{-86}	224	8	2^{-89}	224
	10^9	15	2^{-85}	380	14	2^{-84}	361
7	10^3	5	2^{-86}	144	5	2^{-88}	144
	10^6	7	2^{-86}	202	7	2^{-88}	202
	10^9	12	2^{-85}	321	11	2^{-81}	286

Robustness bounds

Methodology:

- Set the testing time *t*

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Robustness bounds

Methodology:

- Set the testing time t
- Set the number of runs n

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Robustness bounds

Methodology:

- Set the testing time t
- Set the number of runs n
- Choose λ

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Methodology:

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Changing the blockcipher allows to either:

- Reduce λ

Robustness bounds

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Robustness bounds

Methodology:

- Set the testing time t
- Set the number of runs n
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Changing the blockcipher allows to either:

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Robustness bounds

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Robustness bounds

Methodology:

- Set the testing time t
- Set the number of runs n
- Choose λ

$$\Pr[M(x) \neq D(x)] = \left(\frac{n}{t}\right)^{\lambda/2} \leq 2^{-80}$$

Changing the blockcipher allows to either:

- Reduce λ
- Get smaller bound

Robustness bounds

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Outline

Introduction

Private Circuits 3

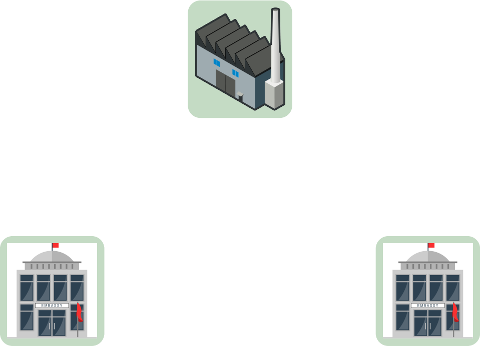
Targeted algorithm

Hardware Design

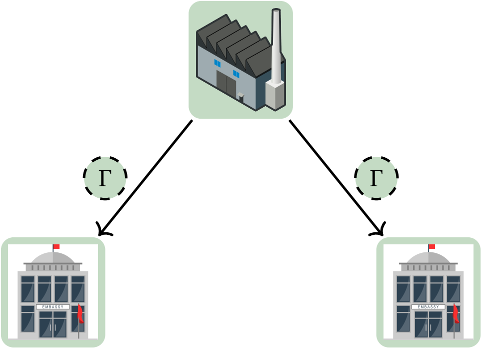
Conclusion

Conclusion

Conclusion



Conclusion



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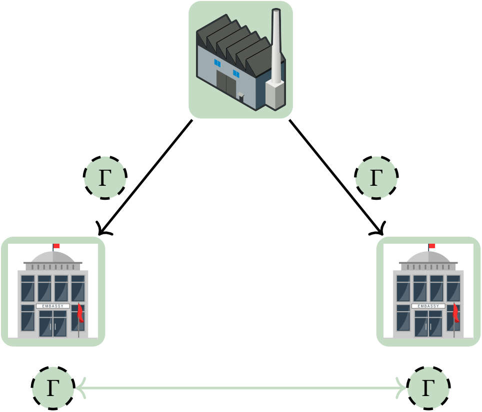

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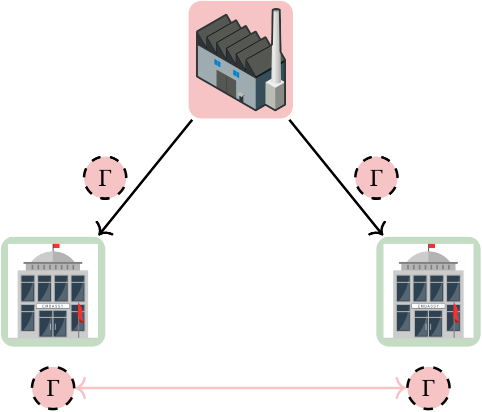

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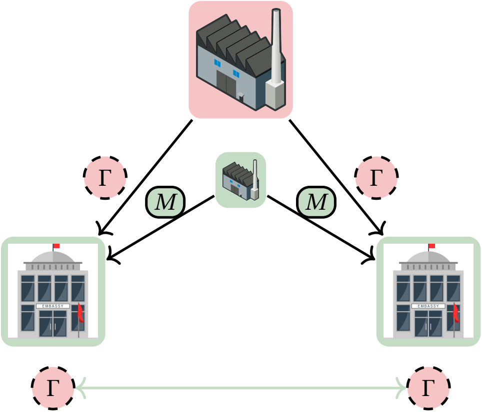

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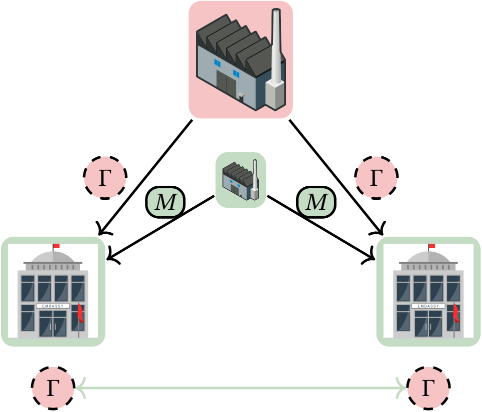

Thank you !

olivier.bronchain@uclouvain.be